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Failure Analysis of Wire Ropes Used in Multi-Wire Machines for Cutting Blocks of Stone

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Abstract

This paper reports the analyses carried out with the company Pedrini SpA ad unico socio, located in Carobbio Degli Angeli, Bergamo (IT). Wire ropes with diamond beads, used as cutting tools in multi-wire machines for cutting blocks of stone, were considered and a failure analysis of the wire ropes was carried out. The aim of the paper is to highlight the damage mechanisms of the wire ropes to increase service life of these cutting tools. Microscope observations and the penetrating liquids method were used to analyze the damaged wire ropes. Fatigue, corrosion and contact fatigue problems were observed and the effect of the centering of the beads on the wire rope was studied.

Article History

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Keywords

Fatigue; Failure Analysis; Microscopic Observation; Penetrating Liquids; Wire Ropes With Diamond Beads.

Introduction

Wire ropes with diamond beads used in machines for cutting blocks of stone are subjected to fatigue, contact fatigue, corrosion and corrosion-fatigue loads in an aggressive environment.

As shown in Figure 1,[1-3] multi-wire machines for cutting blocks of stone are made of two structural main components: the supporting structure, fixed with flanged bolts to the ground, (1 in Figure 1), and a vertical moving part 4 (Figure 1). Several wire ropes with diamond beads are put in motion by a driven drum (2 and 7 in Figure 1). The tensioning mechanical system (9 in Figure 1) allows to apply a tension to the wire ropes with diamond beads while the machine is cutting the stone blocks. Several pulleys guide the wire ropes; up to 80 wire ropes can be used and mounted in parallel on the structural component 4 and on several pulleys. The motorized drum is the component 3 in Figure 1 and a three-phase asynchronous electric motor is mounted on the machine and puts the drum and the wires in motion. Wire ropes with diamond beads are the cutting tools of the machine and the designer must

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take care of such components when mounted on the machine. It is well known that the structural behavior of steel wire ropes, composed of several strands, is complex and multiaxial stresses, along with contact fretting stresses, must be managed. Working conditions of the wire ropes have to be strictly controlled and checked periodically.

Notwithstanding there are many literature references on the study of the damage of wire ropes, few research references can be found, as far as the author knows, that would allow to understand their structural behavior in terms of damage or failure analyses.[4-11] In[4] Authors report a study on the diamond wire cutting of concrete materials. Wire cutting with diamond technique was used in the United States until the early 1980s and allowed to cut reinforced concrete structures, regardless of thickness and reinforcement content. In[5] an innovative and optimized design of automatic adjustment system for beaded rope of new diamond wire sawing machine is reported, while in[6] the mechanics of sawing granite with diamond wire is considered. Research on cutting performance optimization of diamond wire saw is deepened in.[7] In these papers the structural design of the wire rope with diamond beads is introduced and the mechanical structure and control of the adjusting device of the diamond wire saw are described. Working parameters are transmitted via wireless signals to achieve remote control. Mechanics of cutting procedure is deepened and mechanical simulation and optimization models of the wires with diamond beads are proposed. Many references are available on the study of wire ropes without diamond beads;[8-11] such references allow to understand the mechanisms of failure in case of absence of the beads: unfortunately, the Author of this paper found that the structural fatigue and corrosion-contact-fatigue behavior of the wire rope is highly influenced by the presence of the diamond beads.

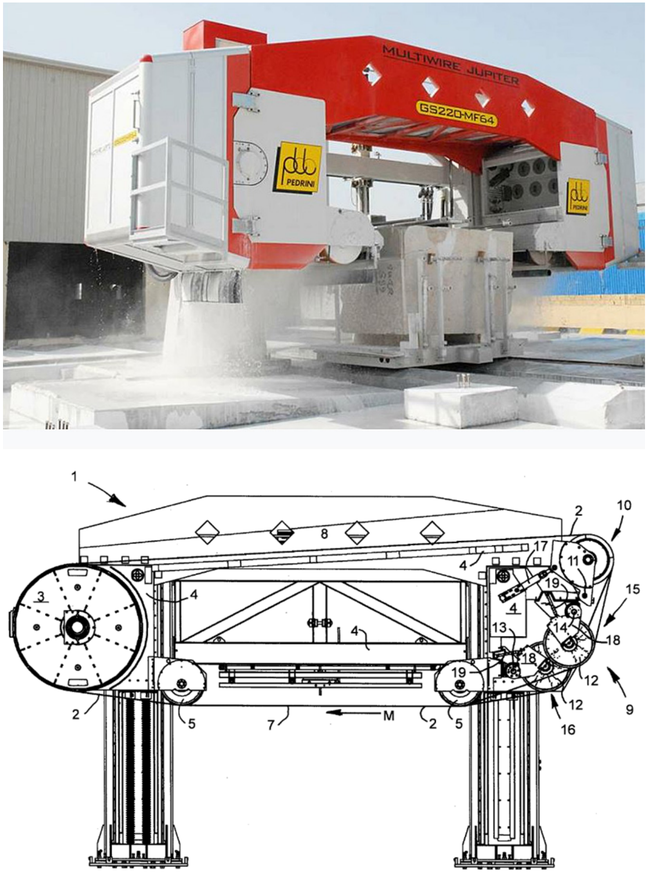

Fig.1: Multi-wire machine for cutting blocks of natural or artificial stone

This paper contains the results of the observation of surface damage of wires used in multi-wire machines for cutting blocks of stone and the optical analysis of beads for 2.35 mm cables. The cables are used as a support for pearls equipped with diamond inserts for cutting stones (beads) (Figure 2).

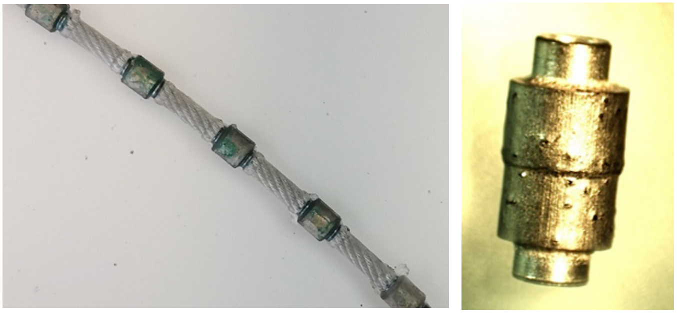

Fig. 2: a) wire with beads and b)bead

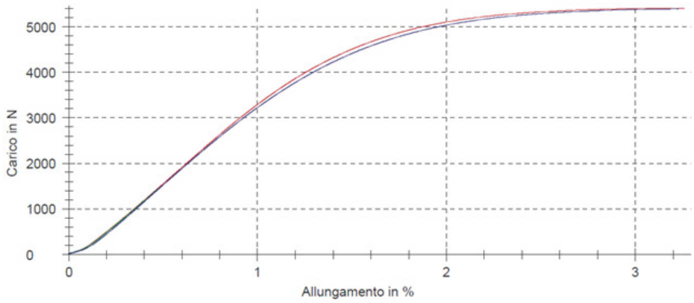

Fig. 3: wire stress-strain curve

Table 1: mechanical features of the wires

	L_0 mm	S_0 mm^2	E_{mod} N/mm^2	$F_{p0,05}$ N	$R_{p0,05}$ N/mm^2	$F_{p0,2}$ N	$R_{p0,02}$ N/mm^2	F_{max} N	R_m N/mm^2
No Zn coating	604	2,46	146000	3785	1540	4159	1690	5410	2200
Zn coating	604	2,65	135000	3785	1430	4159	1570	5410	2040

The analyses and observations under the microscope refer to wires and ropes used by Pedrini multi-wire machines for cutting hard stones (http://www.pedrini-italia.it/). The wires and ropes are produced by different specialized companies, along with the insertion of the diamond beads.

The objective of the observations is to evaluate the surface state and the surface damage of wires and ropes starting from production, use and damage. The wires with beads work hard in a very aggressive environment and the surface state of the same greatly influences the fatigue resistance and could be the cause of premature failure.

The samples were taken from wire ropes having 2,35 mm diameter. The wire rope is composed of 7 strands wires, one of which is located at the centre of the wire rope ("soul"). Each strand contains 7 single wires having 0.3 mm wires diameter (Figure 5).

Mechanical Features of the Wire Ropes

With and without Zn galvanized coating were studied. The mechanical features of the galvanized wires are reported in Figure 3 and Table 1.

Experimental Setup

The study was conducted by means of microscopic analyses and tests with penetrating liquids. For the first, two Leica stereoscopic microscopes (MZ 75 with magnification up to 50x and microscope with magnification up to 40x) with digital camera (Canon Powershot S50 and Canon EOS 1100D) and an Opto-De monofocal optical microscope with magnifications were used up to 400x with Motic 2300 USB 2.0 acquisition camera. A new stereoscopic optical microscope mod. ZENITH SZM-4500 Trinocular Zoom 7x-45x with additional lens 2x mod, ST-087 2x for 14x-90x magnification and a variable double LED illuminator mod. ZENITH CL-31 with double jointed self-standing arm. The images were taken with a USB micro-camera Mod. OPTIKAM B-3 complete with optics.The effectiveness of the protective plastic coating was evaluated by pouring liquids (blue ink) on the cable.

Significant sections of the beaded wire as shown in Figure 4 were investigated. Section X.1 was not considered but we focused on the evaluation of the centering of the cable in the beads. The sections were obtained using a metallographic cutting machine.

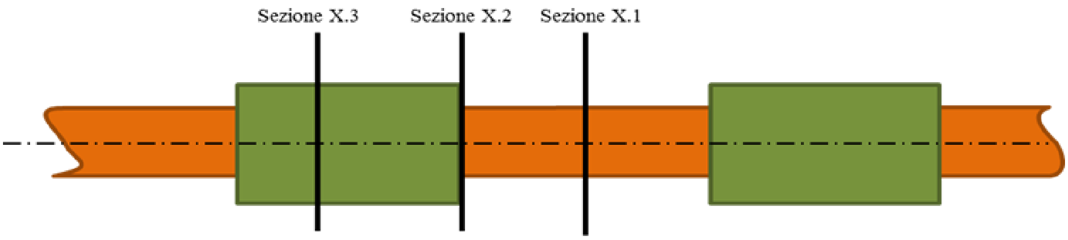

Fig. 4: cut sections of the wire rope with beads

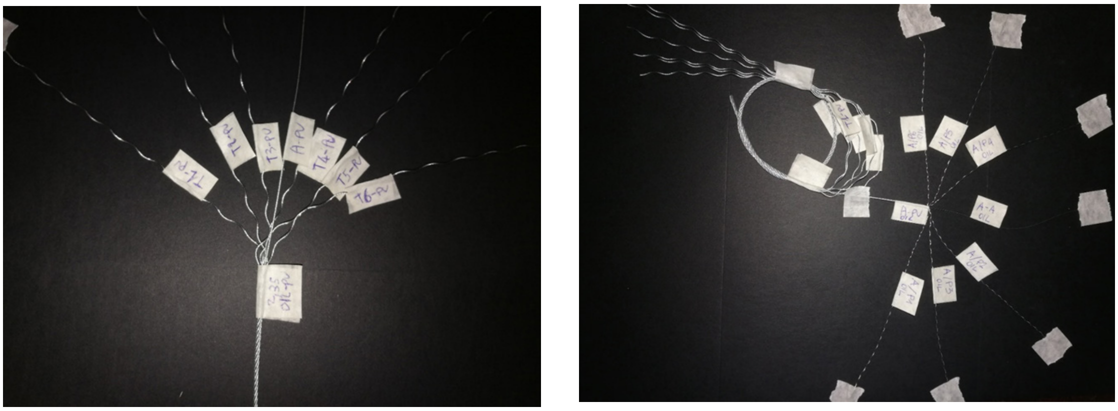

Fig. 5: preparation of a stranded cable and single strands and wires

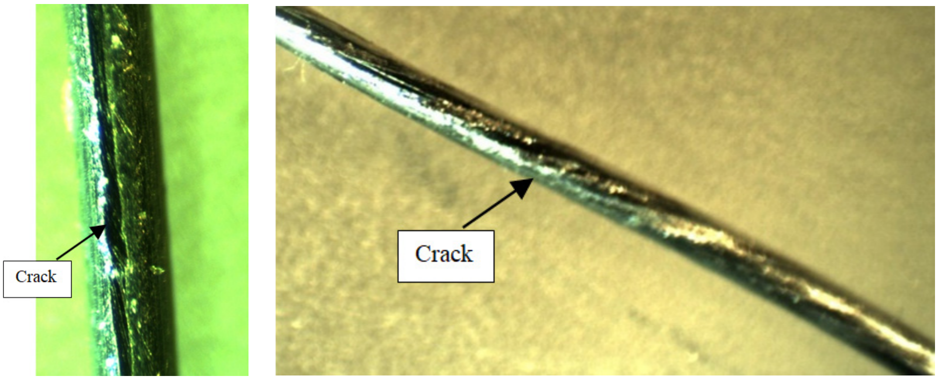

Fig. 6: example of the cracked surfaces of the wires

The wire ropes with beads were also observed by unwinding the strands and the core both by opening the individual strands and by releasing the individual wires before proceeding with the observation. Figure 5 shows two examples of preparation of a stranded cable and single strands and wires.

Microscopic Observations and Results

Figure 6 shows two examples of the cracked surfaces of the wires. Those cracks greatly affect the fatigue resistance of the whole wire rope with beads. Figure 7 shows an example of the cracked surfaces of the rope.

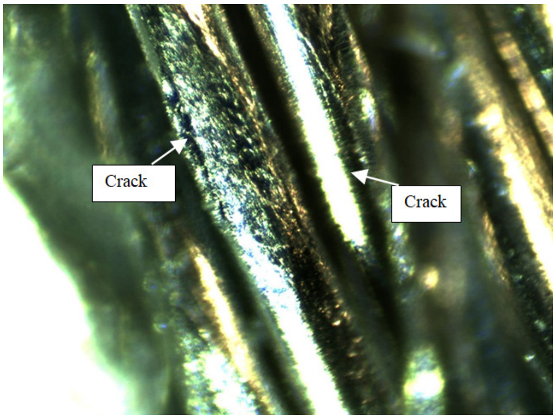

Fig. 7: example of the cracked surfaces of the rope

Fig. 8: penetrating liquids experimental test

To evaluate the effect of the environment on the wire rope, tests were carried out with penetrating liquids (blue ink). Liquids were poured onto the flexed sample to simulate operational behavior. Figure 8 shows the penetrating liquids experimental test.

The centering of the wire rope in the beads was checked too (Figure 9).

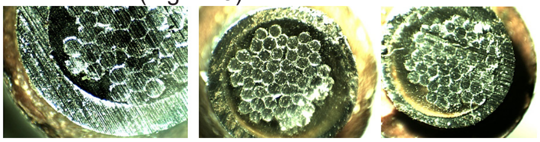

Fig. 9: centering of the wire rope in the beads

Contact between the wire rope and the beads was observed (Figure 9). Beads and the wire rope are made of different materials and this might cause corrosion of the wires in the rope, along with contact fatigue damage.

Analysis of the Results and Discussion

Fatigue Resistance of the Wire Ropes

The wire ropes studied in this work are designed with low fatigue resistance safety factors (2-3). Previous analyses helped in reaching some useful conclusions.[3-10]

Considering a breaking load R_m=2000 MPa, the alternating bending fatigue limit is equal to:

$$\sigma'_{Faf} = \sigma_{Faf}\frac{b_2 b_3}{K_f} = 175\ \text{MPa}$$

Fatigue resistance data:	$\sigma'_{Faf} = \sigma_{Faf}\frac{b_2 b_3}{K_f} = 175\ \text{MPa}$
alternating fatigue limit	$\sigma_{Faf} = 0.5\ R_m$
dimensional coefficient	$b_2 = 1$
surface finish coefficient	$b_3 = 0.7$
fatigue notch coefficient	$K_f = 4.$

If you are considering a pulsating cycle from scratch:

We obtain $\sigma_{m,lim} = \sigma_{a,lim} = 160$ MPa.

The wire rope can therefore withstand very low fatigue loads.

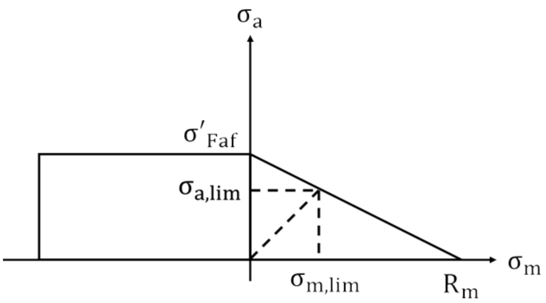

Fig. 10: Haigh diagram, pulsating case from scratch

The entire microscopic analysis revealed:

- Loss of centering of the cable with respect to the bead (stereoscopic microscope
- Widespread and numerous deep grooves and cracks induced by the drawing operation.
- Presence of even very deep cracks.
- Detachment of brass or zinc coatings which, being thin, are unable to adhere to the wire at the cracks. Causes can also be found in the straightening operation and incorrect handling of the ropes.
- Cable-environment interaction as demonstrated by the test with penetrant liquids.
- Scaling of the surface on wires treated with trichlorethylene and ultrasound.
- Shape of the beads not perfectly cylindrical with poor surface finish at the discontinuity.
- Fragments of diamond not homogeneously distributed on the pearl with possible local lifting of materials and consequent detachment of the same.

These conclusions can be drawn:

- The strands can be in contact or not depending on the axial position in the bead, including the core.
- Strands and core rotate on themselves, and the strands rotate around the core as well.
- The strands often encounter the metal base.
- Possible detachments are observed between the metal base and the diamond paste.
- The diamond paste has no uniform thickness, with a maximum ratio that can reach 2:1. Where the thickness is smaller, a lower density of diamonds is observed. This could be the cause of the ovality of the bead.

Discussion of the Results

Observations and analysis of the damaged wire ropes allowed to highlight that the beads have no continuous side surface and at the discontinuity the finish is very poor. Moreover the insertion of the diamond chips is not uniform. The insertion of the splinters causes localized lifting of the material. This could cause premature detachment of some of them. Wire ropes are mechanical components that work in a complex stress state with contact loads, wear, corrosion and fatigue resistance problems. The presence of the diamond beads is a further stress concentration, with corrosion and contact wear fatigue problems if the beads come into contact with the wire rope during assembly or in working condition.

The advice is to product wire ropes with beads in which the centering of the cable with respect to the bead is carefully controlled. No contact between rope and bead should occur. According to the results and observations this is the most important advice for producers of the ropes with diamond beads.

Conclusions

This paper reports the failure analysis of the damage mechanisms of wire ropes with diamond beads mounted in machines for cutting stones. Wire ropes with diamond bead are cutting tools subjected to fatigue, corrosion-contact-fatigue stresses. Cracks and defects are present in the strands of the wire ropes, generated during the production process: these cracks are further sources of stress concentrations. The observation at the microscope, and the penetrating liquids analyses, highlighted that the most important advice to give to the producers of the wire ropes with diamond beads is to product components in which the centering of the cable with respect to the bead is carefully controlled.

Acknowledgments

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With almost 60 years of experience in the stone field, Pedrini is an international leader in the manufacturing of machines for the processing of

natural stone, designing and supplying complete plants.

The experience achieved through continuous investments in technology, research and innovation enabled Pedrini to improve the quality and reliability of its machinery thus becoming a valid reference point on the worldwide market.

Pedrini's technical department can count on about 20 professionals, among which engineers and specialized technicians, operating with the most advanced instruments and software for mechanic and electronic design.

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Conflict of interest

The author declares that there is no conflict of interest.

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